Flood Susceptibility Assessment of Wyra River Catchment, South India using AHP-GIS Multi Criteria Approach

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Abstract
Floods can create natural disasters that cause widespread damage such as destroying people's lives and resources in the social and environmental domains. Flooding is extreme and periodic due to climate change and the acceleration of human-influenced land-use modification, which increases the force in the river pathways and due to these alterations, the river morphology changes. To reduce flood damage, mapping and analysis of flood susceptibility are crucial components of flood reduction and mitigation procedures which recognize most at-risk regions according to physical features that identify the probability of inundation.

With the use of geographic information systems (GIS), multi-criteria decision analysis (MCDA), analytical hierarchy process (AHP) and remote sensing (RS), this study attempts to generate a map of the Wyra catchment's flood risk. Nine thematic maps have been developed: slope, soil type, elevation, land use/land cover, topographic wetness index, rainfall and distance from rivers, drainage density and road distance maps. The Wyra catchment area is about 3443 km^2. According to this research, about 11.60% were in a zone of risk, vulnerable to flooding. Around 84.33% and 4.06% were moderate and low-risk zones respectively. This study provides efficiency in terms of time and funds for the flooding procedure in the catchment of Wyra. As a result, flood forecasting, early detection and control will be helpful for planners of land use and decision-makers to lessen the effects of flood vulnerability and future damages within the Wyra watershed.

Keywords: Analytical hierarchy process, Flood Susceptibility mapping, Geographic information system, Land use/land cover, Wyra catchment.

Introduction

Floods can cause natural disasters such as fatalities and infrastructural, economic and social disruptions, huge damage to construction and casualties worldwide. The efficiency of the flood is an outcome of various requirements including flood power, frequency, size, the length of the flow, the river's cross-section geometry, changes in the plan form etc.[43] Floods have occurred frequently because of climate change, quick urbanization and the degradation of land use management[12,25]. In India, floods are very regular; they cause human losses and agricultural damage[5,30]. Floods cause destruction each year, affecting around 170 million individuals globally. Due to climate change, floods can be disastrous and extremely dynamic[8]. Climate circumstances significantly influence a river's runoff.

Research studies have identified that peak discharges typically determine the effectiveness, frequency and severity of floods[23]. The estimation of flood, depending on the regulating variables and effectiveness, varies from one river to another. Temporary susceptibility maps can decrease flood-related economic losses and fatalities. Susceptibility maps are used to prevent future damage. Around eight million hectares of India's land are impacted by floods yearly[33]. Therefore, adequate flood management is required to mitigate those geographic areas and their corresponding socio-economic limitations[19]. In river catchments, flood hazards are influenced by the high annual rainfall rate, resulting in fatalities and significant destruction of property[26]. This damage is caused by high precipitation rates, high groundwater levels, huge quantities of river flows and high tide levels[1].

Although catastrophes cannot be excluded, proper planning and an effective management approach could be beneficial to decrease the devastation. Hence, the recognition of vulnerable areas is a useful method in any strategy for mitigating disasters[9]. The consequences of flooding are the recurrence that there might be more floods because of drainage channel changes, irregular drainage basin planning, heavy rainfall, urbanization, deforestation etc.[42] Different parameters that cause flooding are massive rainfall, climate change, less soil permeability, modifications in land use patterns etc.[7] A flood can generate various losses, such as infrastructural losses (communication networks, transportation networks), agricultural losses (crop loss, damages to land, productivity), public facility losses, property loss and availability as well as an effect on water quality and accessibility[38].

Due to floods, there are various effects such as drowning and direct and indirect health effects because of displacement of population, lower income and inadequate interim living conditions[7]. In India, floods destroy almost forty million hectares of land[17]. During the southwest monsoon season between July and October, it receives 75% of the precipitation, most of the river's overspill during this session because of this flooding[2]. After Bangladesh, India is an extremely affected country in the world[29]. Developing accurate flood susceptibility maps will be useful to reduce flood risk, as losses and dangers can be decreased. Mapping flood susceptibility is necessary for mitigation plans, hence, it will find out the most susceptible places and the physical features that are influenced by floods[44]. Floods are an element of the water cycle; therefore, the impact of flooding, frequency and magnitude have increased in recent periods[22].

Flood vulnerability mapping and analysis are used to find components of an early warning system (or) mitigation of flood situations, so it recognizes that the vulnerable area depends on the physical environment and propensity for flooding[44]. The combination of remote sensing (RS) and geographic information systems (GIS) methods is beneficial for different aspects of environmental analysis[15,28]. Recent studies concluded that RS and GIS methods are more appropriate for producing maps of flood susceptibility with good accuracy[48,49].

However, various methods have been used, there has been widespread use of the analytical hierarchy process (AHP)[13,40]. During the previous 20 years, the evaluation of flood risk has been done by various river catchments, implementing the AHP[10,12], frequency ratio and artificial neural networks[36,44,45]. The RS and GIS methods have been extensively used in disaster management investigations, specifically related to floods[27].

Flood susceptibility analysis is done using multi-criteria decision analysis (MCDA)[40]. Methodologies for allocating weights, or weighting techniques pairwise, for example, can be utilized in MCDA to estimate the significance of the chosen conditioning elements[24,41]. Considering a variety of evaluations of published work, the most common MCDA technique in terms of delineating zones susceptible to flooding is those with a weighted linear combination[21]. The AHP method is the most adopted technique for determining weights which used pairwise estimation to determine how much one differs from the other in terms of ranking on the specified criteria[33].

To fully understand urban green area’s potential significance, it is imperative to quantify the benefits they provide in terms of economic gains and flood mitigation. Flood-resistant urban planning should prioritize solutions derived from nature that is, promoting blue and green spaces in cities, due to their numerous ecosystem advantages. For watershed hydrology, the GIS environment offers a potent tool. It is adopted and simply deployed to vast research areas, facilitating the collection of all data and information into a single database for watershed characterization and spatial analysis. The MCDA-based AHP method is used[14].

Various approaches are utilized in the mapping of flood susceptibility[22]. The geomorphologic characteristics of the catchment have been employed in various studies[35]. Although this technique cannot substitute traditional hydraulic modeling[32], it could be adopted, specifically in in-depth research or in developing nations[4].

Techniques like frequency ratio and logistic regression based on expected input parameters depend on different emphasizing criteria like the number of data sets[31,37]. Advanced technologies like algorithms for machine learning might use random forests, support vector machines, or artificial networks[43]. This research aims to present the areas that are susceptible to flooding in Wyra catchment by using RS and GIS by integrating with AHP methods. Nine influencing parameters: soil type, elevation, slope angle, land use/cover, topographic wetness index, drainage density rainfall, distance from river and distance from roads, have been used for process mapping which creates a flood susceptibility map. This is useful for land use planners and decision-makers and it is also useful for disaster management teams for identifying flood-affected zones within the research area.

Study Area

The Wyra catchment spread in Telangana and the Andhra Pradesh region of the Southern peninsula of India is shown in figure 1. The Wyra River is formed by combining two major streams, the Moddupadava stream and Nimma stream. The two streams originate in the region in the Northern Ghats on the hill located in the south-west of the Khammam district. Wyra River is one of the rivulets of the Munneru River. The Wyra catchment is situated between a latitude of 16^0 14' N and 17^0 35' N, a longitude of 80^0 05' E and 80^0 55' E. It has a catchment area of about 3, 443 km^2 which itself is affected by hot summers and winter seasons. The Wyra River flows in a south direction in Madhira mandal to join the Munneru River in Krishna district. The region has a dendritic to sub-dendritic drainage system.

The crops in the Wyra catchment are jowar, rice, maize and pulses. The irrigation potential of the basin was utilized and constructed for the Wyra medium irrigation project, which was constructed across the Wyra River by the Nizam Government. The project used for irrigation, is in the Wyra, Thallada and Bonakal mandals of Khammam district, covering 24 villages and a total area of 7,038 hectares. The rivulet drains into the Munneru River after 65 km of its journey. The Wyra catchment experiences average annual rainfall that varies between 1012-1255 mm between (2011 - 2020). Elevation differs between 28 m and 785 m. The sandy-clay-loam, clay-loam and clay soil types are found in the basin.

The peninsular Gneissic complex covers 81.32 %, Charnockite covers 9.06 %, Khondalite covers 3.50 % and Lower Gondwana covers 3.58%. Wyra catchment encompasses major towns in Telangana such as Khammam, Kothagudam, Madhira, Vijayawada, Jaggayyapeta, Tiruvuru and Nandigma and Yellandu of Andhra Pradesh. Taluk wise area that will be covered by the Wyra river is summarized in table 1.

Material and Methodology

Flood susceptibility mapping was generated using different input data obtained from various sources and put together in GIS. Digital elevation model (DEM) high data resolution from the website NASA, RS and GIS have been used for analysis and prepared maps like elevation, slope, drainage density and topographic wetness index map (TWI). Land use and land cover (LULC) data were obtained from Sentinel-2 with a 10 m resolution, obtained from the ESRI land cover website. Soil data from the FAO website, distance from river and roads from DIVA-GIS and rainfall data were obtained from CRUTS v.4.07 high-resolution gridded datasets. Based on various literature studies and their significance on susceptibility to flooding, nine flood control elements were chosen to obtain appropriate data and to avoid an excess of validity in spatial modelling at a national basis. Elevation, slope, LULC, rainfall data, soil type, TWI, distance from the river, drainage density and distance from road maps were developed from data and integrated into GIS and finally, the output is a flood susceptibility map. Flood mapping is the main methodology, adopted using GIS setup and MCDA analysis. Figure 2 represents stage wise methodology of the current study. The methods adopted in this research make use of the potential of GIS in the management of geographic data and the flexibility of knowledge-based MCDA to incorporate value-based agreements with real details. According to a comprehensive overview of the literature, a total of selected nine flood-controlling components regarding susceptibility mapping, are considered in this research.

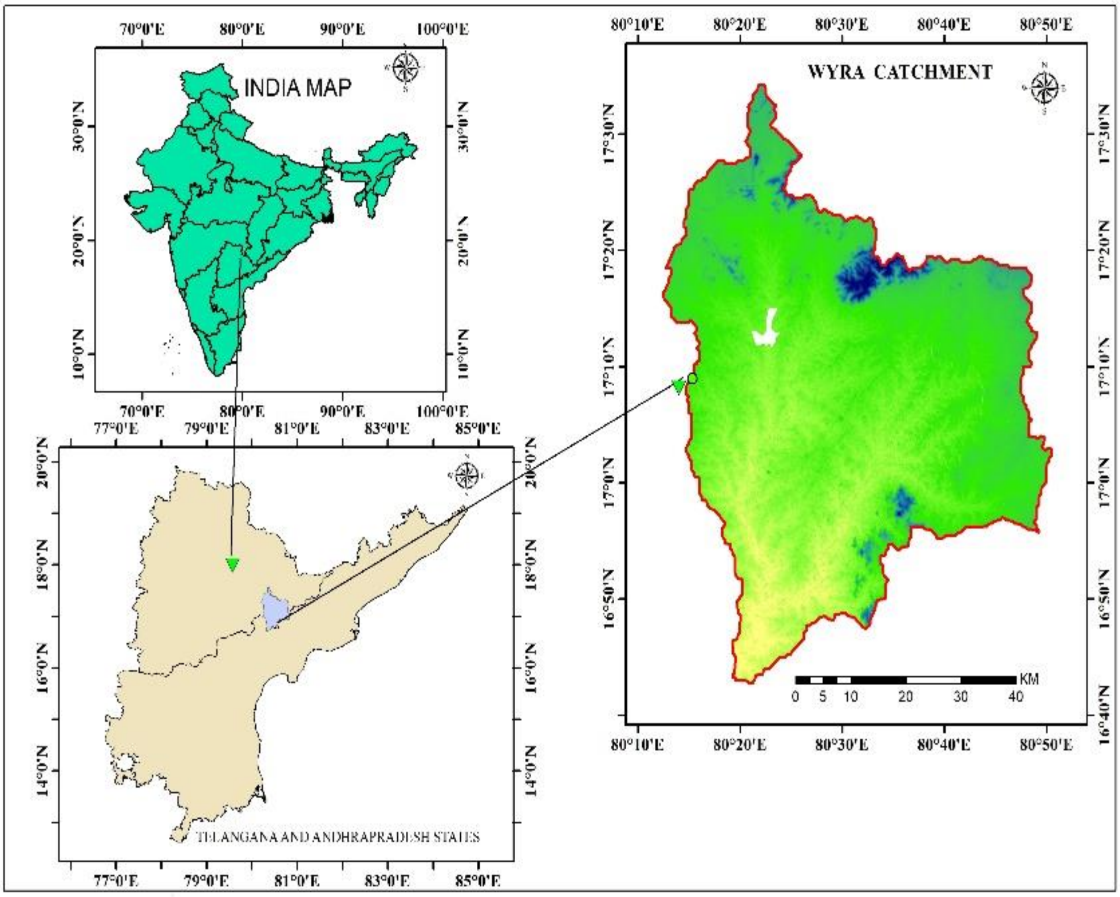


Fig. 1: Geographical location of Wyra Catchment from Andhra Pradesh

Table 1
Area of the Wyra catchment details Taluk-wise

S.N.	State	Taluk	Area (Sq. km)	area (%)
1	Telangana	Khammam	329.47	9.56
2	Telangana	Kothagudem	409.86	11.9
3	Telangana	Madhira	1534	44.56
4	Telangana	Yellandu	305.21	8.86
5	Andhra Pradesh	Jaggayyapeta	4.01	0.116
6	Andhra Pradesh	Nandigama	135.94	3.947
7	Andhra Pradesh	Tiruvuru	717.111	20.82
8	Andhra Pradesh	Vijayawada	7.88	0.22

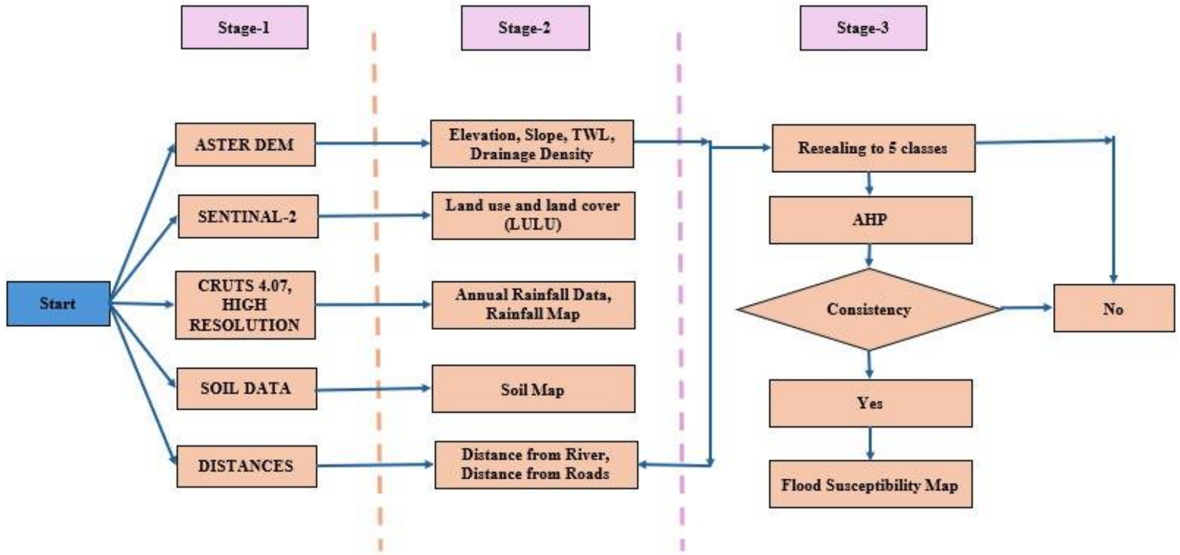


Fig. 2: Diagram showing the process for locating and mapping regions that are vulnerable to flooding

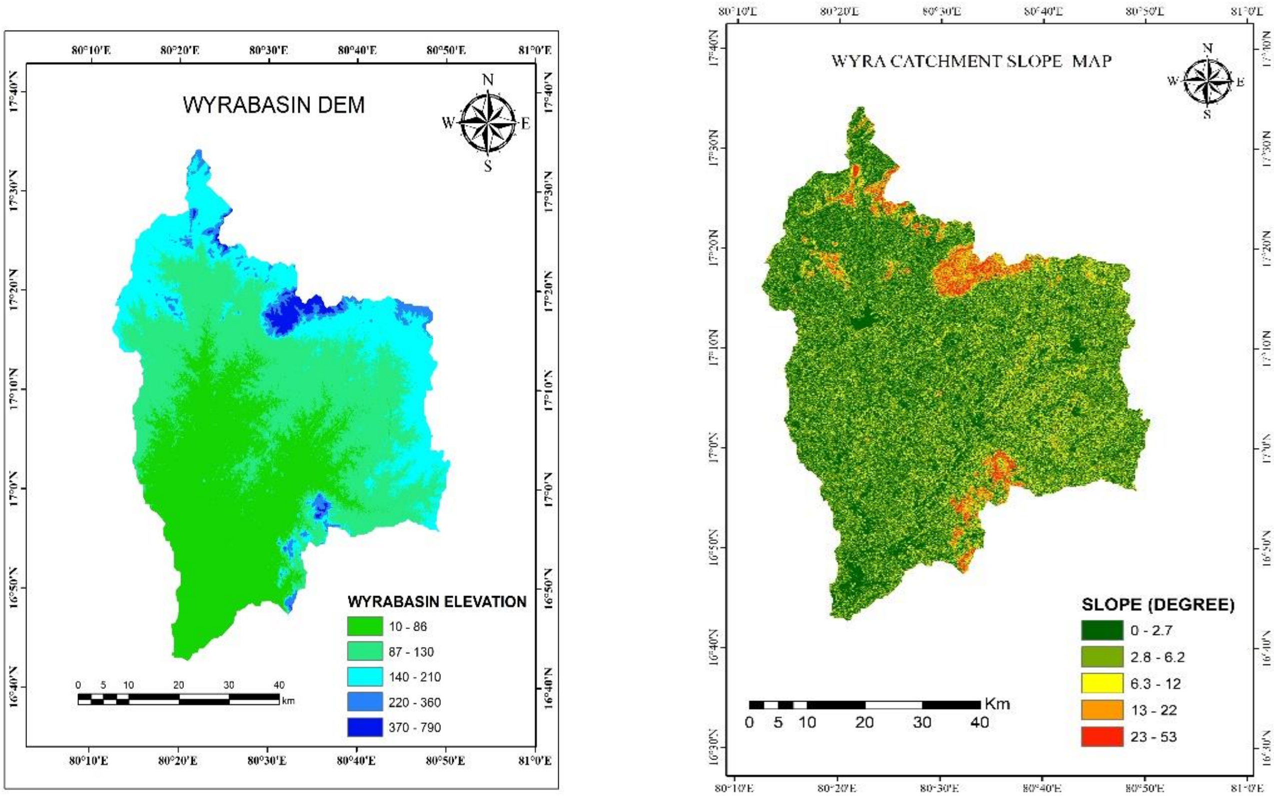


Fig. 3: Spatial distribution maps showing the elevation and slope of the Wyra Catchment

Results and Discussion

Surface and flow characteristics of Wyra catchment: Flood control parameters used in the research are surface characteristics and flow characteristics such as elevation, slope, LULC, soil map, TWI, rainfall map, drainage density, distance from the river and distance from the road. They were utilized to develop the potential area's susceptibility to floods. Mapping the research area's susceptibility to flooding through an investigation of these factors, a more specific analysis of each parameter is represented as follows:

Elevation: The study region is located between 10 m and 790 m above sea level. Elevation is among the parameters employed to identify the risk of flooding in the study region. Downsized-elevation regions have an increased probability of flooding incidents than greater-elevated areas. Lower altitudes are generally associated with maximum discharge and are submerged quicker by the flow of flooding than higher altitudes. Elevation is inversely proportional to flooding. Areas with lower elevations can be found in the southeast and southwest elements of the research region:

very low, low, moderate, high and very high, 1.1%, 3%, 22%, 38% and 36% elevation of the research area.

Slope map: The gradient controls the surface flow velocity. High slopes reduce flow accumulation. Lower slopes increase the probability of flooding. The slopes in mountainous regions are typically steeper, preventing water accumulation, in contrast, the likelihood of floodinundation is higher in low lands or flat lands with gentle slopes[46]. There is a correlation between surface flow velocity and the research area's slope and the slope partially regulates the intrusion process. Slope can regulate flow in downward directions. DEM generates slope maps within the ArcGIS by utilizing framework surface-level instruments, Figure 3 represents slope map of the catchment that covers the study region's 44% (1519.82 sq km) having a slope ranging from 0 to 2.7^0 related to an extremely high susceptibility to overflowing floods. Around 37% (1268.66 sq. km) and 14% (472.88 sq. km) within the research region are categorized as high (2.72^0-6.45^0) and moderate (6.46^0- 12.7^0) susceptible to flooding correspondingly. Areas of low (12.8^0 to 22.1^0) and very low (22.1^0 to 53.1^0) show susceptibility to floods.

Land use and Land cover (LULC) mapping of Wyra Catchment: Flood occurrence is managed by LULC; it is one of the crucial parameters. Because vegetation decreases water flow and induces maximum infiltration, regions with massive vegetation are less susceptible to flooding. Runoff is higher in residential and urban zones due to impervious surfaces and less infiltration[6,11]. LULC of different surfaces, areas with very high, moderate, low and very low sensitivity to floods include water bodies, urban areas, bare ground, agriculture and shrubland[6].

Figure 4 shows the LULC map of the investigation region which is classified as very high (water body), high (built up, flooded vegetation) and moderate (crops, bare ground, range land), indicating more vulnerability to flooding. Most of the lands in the Wyra catchment are observed to be cropland, considering 75.70% of the research region, water bodies, trees, 2.54%, 10.9%, built up 4.8% and range land 5.89% respectively.

Soil Type: Soil texture influences hydraulic conductivities; the fine-grained soil decreases infiltration and intensifies surface runoff. Therefore, regions with a fine soil texture influence more floods than regions with a rough soil texture[6,16]. The kinds of soil in the research region are categorized as low, moderate and susceptible to floods. In this study region, typically, four different classes of soil are identified, as represented in figure 4. Sandy Loam (moderate), loam (moderate), clay (low) and clay-loam (low) are susceptible to flooding covering about 45.89%, 28.05%, 3.75% and 22.29% of the study region respectively.

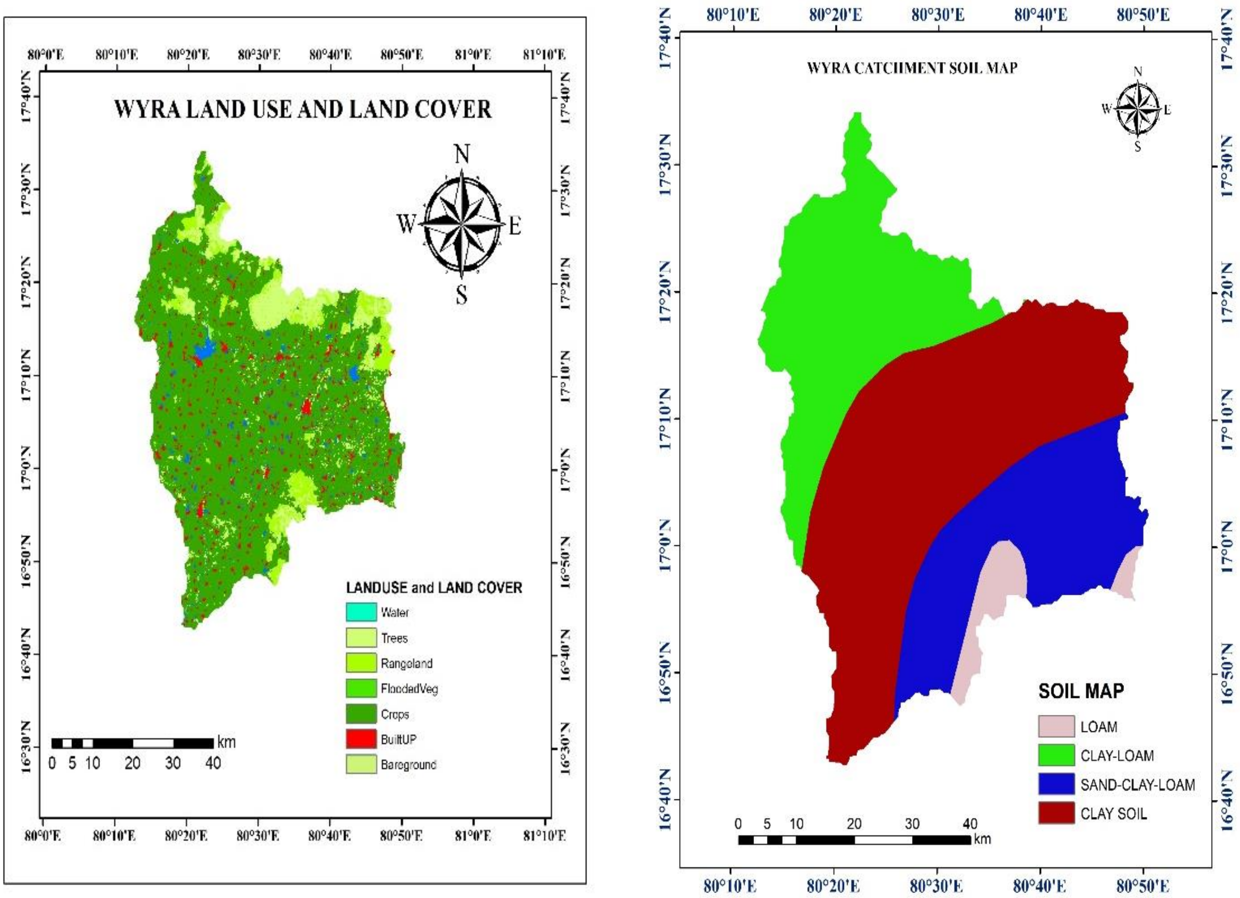


Fig. 4: Wyra Catchment LULC and Soil Map

Topographic Wetness Index (TWI): The Wyra catchment's TWI map was created using the equation 1 and the raster calculator function of the spatial analyst tools in the ArcGIS environment was used to build the TWI map.

$$W = Ln\frac{As}{tanB} \quad (1)$$

where W indicates the TWI and notation (B) is the degree of the local slope angle. The TWI is adapted to represent flow accumulation volume at any location and the physical resemblance of the area inundated by floods. The relationship between TWI and flood risk is direct. The TWI of the region and geomorphology have a strong correlation. Larger TWI values indicate a generally higher likelihood of flood inundation[6]. The TWI of the research region was divided into five categories of flooding susceptibility grouped as very low (-8.4 - -5), low (-4.99 - -2.99), moderate (-2.98 - -0.46), high (-0.459 - 3.12) and very high (3.13-13.8) covering 39.06%, 32.89%, 14.82%, 10.81% and 2.40% of the study region. The TWI of the Wyra catchment is shown in figure 5 and the corresponding weight obtained using weighted overlay techniques is given in table 5.

Rainfall Map: Flood susceptibility mapping analysis and rainfall mapping are the most significant parameters studied by various researchers worldwide. A research study indicates that a relationship exists between flood occurrence and rainfall in the study area. Flooding occurs due to heavy rainfall or long periods of rainfall and because of this, high runoff is generated in the catchment area. The study region's rainfall ranges from 1000-1094 and 1201-1255 mm/year, the spatial distribution of the rainfall intensity of Wyra Catchment is shown in figure 5.

The TWI and rainfall map have been reclassified to a maximum scale of 5 since it is required in weighted overlay technique, after re-scaling the rainfall intensity into 5 classes which include very low (1012-1094 mm), low (1095-1,131 mm), moderate (1,132-1,166 mm), high (1,167-1200 mm) and very high (1201-1255 mm). The northeast and northwest of Wyra Catchment area are highly susceptible to floods.

Drainage density mapping: The drainage density is one of the variables that influences storm susceptibility. The drainage system of the research area depends on several variables including slope, kind of bedrock and fracture patterns both locally and regionally. Soil permeability is an inverse function of drainage density. A minimum porous surface area is vulnerable to maximum drainage density which leads to large runoff from rain and the reverse way around. Accordingly, an increased drainage density suggests that the area is at a lower risk of flooding. Therefore, as drainage density is enhanced, the rating for density of drainage reduces. The stream's whole length segment separated by the area unit is the drainage density.

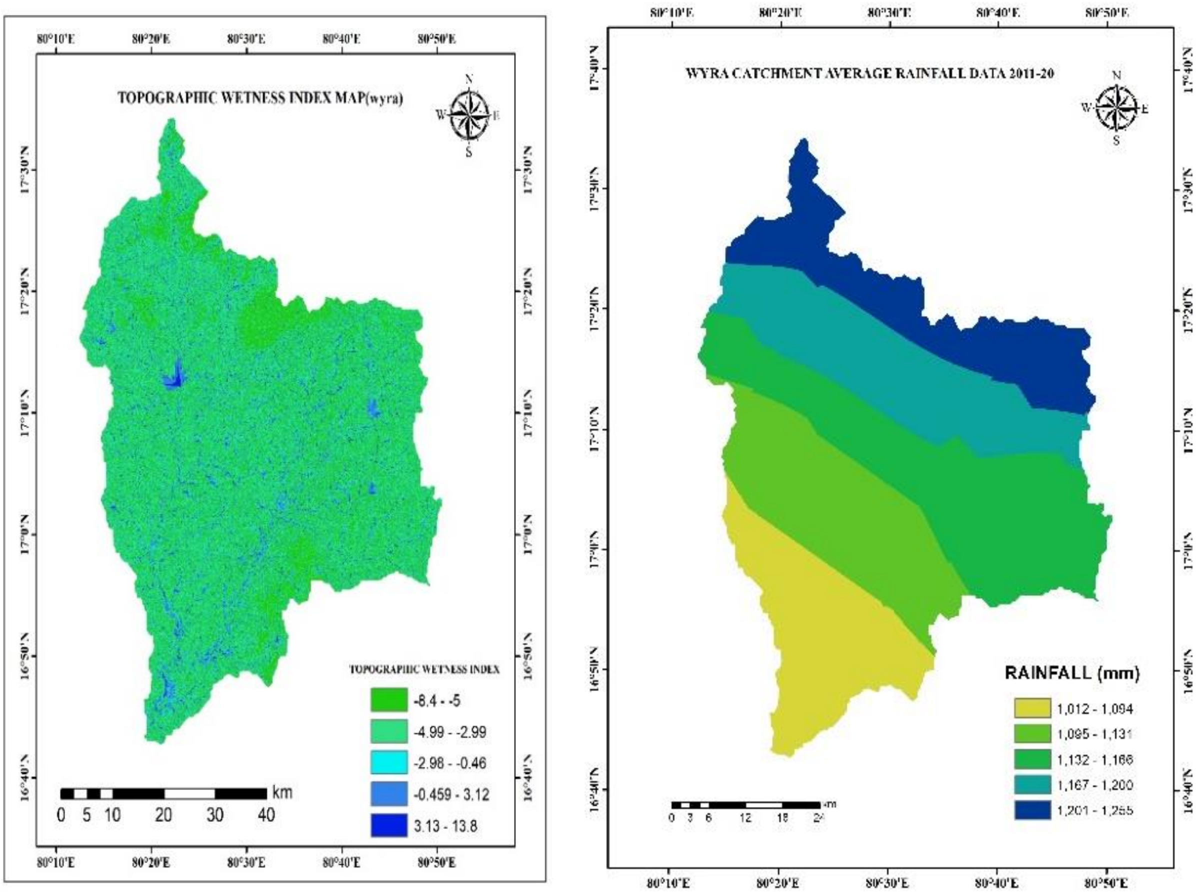


Fig. 5: Wyra Catchment Topographic Wetness Index and Rain Fall Map

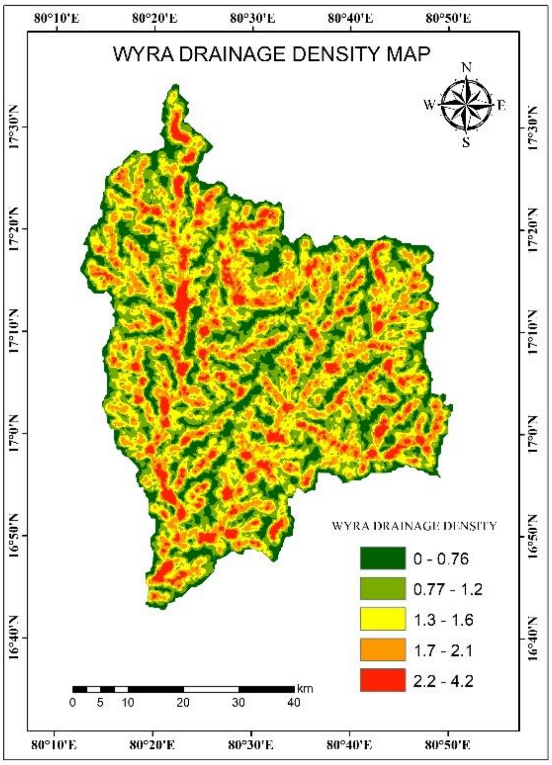
In the spatial analysis tool, using ArcGIS method to retrieve drainage systems from DEM with an improvement of 30 m utilizing the stream polyline feature and kernel density, a drainage density region was calculated in using GIS. Finally, the drainage density was classified continuously according to the flood vulnerability index. In the Wyra basin, the drainage density varies from 0 - 4.21 km/km^2. The drainage basin is split up into five classes considering how it affects flood susceptibility: very low (0-0.75), low (0.76-1.2), moderate (1.21-1.62), high (1.63-2.06) and vary high (2.07-4.21) km/km^2 as shown in figure 6. Each class of the drainage density indicates about 36.92%, 37.70%, 21.64%, 3.28% and 1.42% of the watershed's total area, the weights of the drainage density are summarized in table 5.

Distance from River mapping: Flood inundation occurred in an area near the river basin, then away from the river catchment. Therefore, rivers initially cause damage along the riverside and then adjacent lowland areas. Areas around 500 m are more vulnerable to flooding than regions far away from the study region. River regions like 1000 m, 1500 m and >2000 m, are categorized into high,moderate, low and very low susceptibilities to floods, as shown in figure 6. Each class can be divided into five categories: 29.66%, 27.10%, 21.84%, 13.78% and 7.60% respectively as very high, high, moderate, low and very low susceptibility to floods.

Distance from roads: Distance from the road is another crucial consideration when identifying areas that could experience flash flooding. Roads impede water from penetrating the earth, slowing down the infiltration process. As a result, many roads get flooded by light rains which lead to flash floods. Additionally, because of less penetration and a quicker runoff process, areas near roads are highly susceptible to sudden flooding. In the research region, distances from roads were re-classified as very high (0 - 1950 m), high (1960 - 4210 m), moderate (4,220 - 6,710 m), low (6,720 -11,300 m) and very low (11,400 - 19,900 m) respectively. The distance from roads is mapped and shown in figure 7 and the corresponding weights of each distance class are summarized in table 5.

Analytical Hierarchy Process (AHP): The most regularly adopted and successful method is developed by the AHP in which MCDM processes determine the corresponding criteria significance (or) element reflected during the research and several previous investigations have been performed[3,6,34]. This technique is used to weigh each flood-control element and, finally, to determine and identify the locations most vulnerable to flooding. As per this analysis, flood susceptibility mapping, making use of MCDA, is adopted. Weights are set according to the regional physical features of the research region and the evaluation of former investigations.

As recommended, following procedure was used to assign a related weight for every flood control component that was utilized in the research[34]. In the matrix for pairwise comparison (Table 2), developed according to the corresponding significance, a value arranged on a scale of 1 to 9 was allocated to every component to build. The scale is 1 point for similar importance and 9 points for major importance.



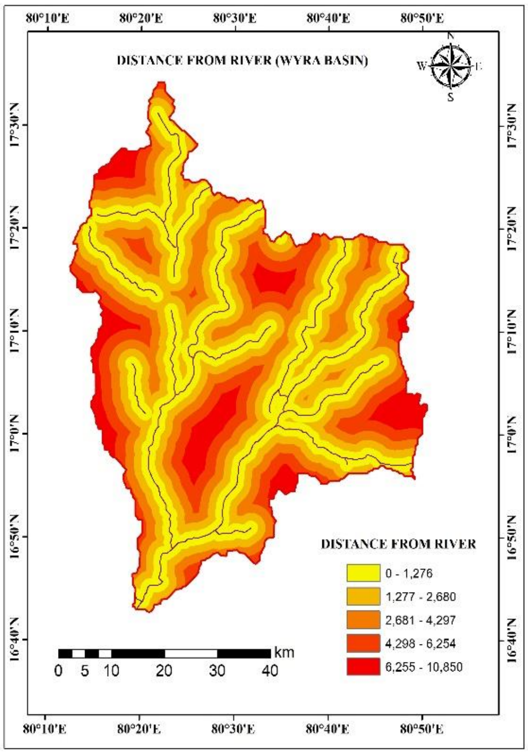


Fig. 6: Drainage density and distance from river maps of the Wyra Catchment

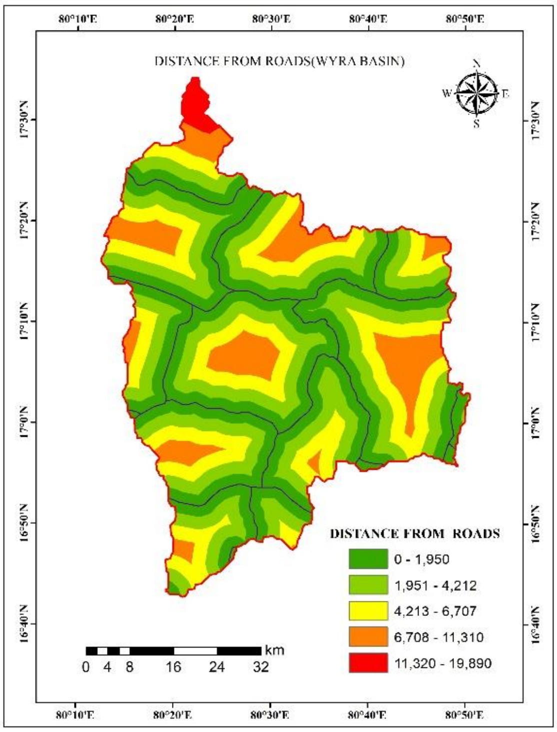


Fig. 7: Wyra Catchment Distance from Roads

Afterward, each value in the matrix of pairwise comparisons column was separated by the total of the column values to produce the normalized matrix table for pairwise comparisons. The weight of each element was calculated in the third stage by dividing the amount of each row by the number of components in the normalized pairwise comparison matrix tables (Table 3). Following the computation of weights for each flood control element, a consistency check was conducted using the weights (eq. 2) stated below to ascertain whether the comparison was accurate and consistent. The following formula is used to determine the consistency index[34]:

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{2}$$

where the consistency index is (CI). Eigen values denote the number of elements being contrasted in the matrix. As recommended, the following approach was utilized to get the comparative matrix's (Table 4) greatest Eigen values[34]. Combine the numbers in the rows to get the weighted sum value. Every weighted total value's ratio to the corresponding aggregate value is based on the criteria weight, divide by the criteria weight and finally the consistency ratio (CR) was calculated with the help of eq. 3 which is recommended to check the consistency of the comparison[34].

$$CR = \frac{CI}{RI} \tag{3}$$

$$RI = W_1R_1 + W_2R_2 + W_3R_3 + W_4R_4 + W_5R_5 + W_6R_6 + W_7R_7 + W_8R_8 + W_9R_9 \tag{4}$$

where CR is the consistency-to-ratio, CI is the index of consistency. The random index (RI) $W_1 \times R_1$, $W_2 \times R_2$ ……… $W_9 \times R_9$ are the weighted and ranking of elevation, slope, LULC, soil type, TWI, rainfall, drainage density, distance from river and distance from road respectively.

Flood susceptibility mapping of the Wyra Catchment: Once each flood-controlling element was developed and re-classified to a common scale of measurement ranging from very low to very high on scale of 1 to 5, using ArcGIS software and weighting the elements using the AHP method, the spatial layers were combined and overlaid jointly in the ArcGIS spatial analyst extension using the weighted overlay method. The flood susceptibility map of the study region was obtained by applying the equation 5 used in much earlier research to create the flood vulnerability map[6,11]:

$$Fs = \sum_{i=0}^{n} X_i \times W_i \tag{5}$$

where FS is the flood susceptibility, notation (n) is the number of decision criteria and X_i is the normalized criteria. The rater layers' pixel/cell values are multiplied by their weights or percentage effect. The flood susceptibility is produced by adding the results which are obtained using the AHP approach.

Implementing AHP techniques for Wyra catchment analysis: Re-classification of all the elements that control flooding and AHP analysis were utilized to the equivalent weights that affect the storm surge controlling variables that are weighted overlay. A matrix of comparison was created as indicated in table 2. The pairwise comparison's normalization and the factor weights were calculated as presented in table 3 and additionally, the comparison's consistency was checked by the recommended process[34]. Table 4 indicates the final criteria weights for every element preventing flooding, it shows how much each element is thought to influence the possibility of floods in the research region.

Therefore, the elevation is 12%, the slope of the research domain is 11%, the LULC10%, the soil type is 10%, the TWI is 13%, the rainfall within the region is 14%, the drainage density is km/km^2 10%, the distance from the river is 13% and the distance from roads is 8%. The consistency index (CI = 0.06) was determined by utilizing equation 2 and the consistency ratio (CR = 0.041) was measured with equation 3.

Before estimating CI, the computed greatest Eigen value (9.48) and several elements (here n=9) were applied. The random index (RI) varies based on number of parameters used for analysis and in this study, the RI is1.46 for nine variables[47].

Table 2
Matrices for pairwise comparison

Factors	El	Sl	LULC	ST	TWI	RF	DD	D-river	D-road
El	1	1	2	1	1	1	1	1	3
Sl	1	1	3	1	1	1	1	1/2	1
LULC	1/2	1/3	1	1	1/3	1/3	1	1/3	3
ST	1	1	1	1	1	1	1	1	1
TWI	1	1	3	1	1	1	1	1	3
RF	1	1	3	1	1	1	1	2	3
DD	1	1	1	1	1	1	1	1	1
D-river	1	2	3	1	1	1/2	1	1	3
D-road	1/3	1	1/3	1	1/3	1/3	1	1/3	1
Sum	7.8	9.3	17.3	9	7.6	7.1	9	8.1	19

Table 3
Normalized pairwise comparison matrix

Factors	El	Sl	LULC	ST	TWI	RF	DD	D-river	D-road	Sum	CW	CW %
El	0.128	0.107	0.11	0.111	0.131	0.140	0.111	0.123	0.157	1.118	0.124	12.4
Sl	0.128	0.107	0.173	0.111	0.131	0.140	0.111	0.061	0.052	1.014	0.112	11.2
LULC	0.064	0.032	0.057	0.111	0.039	0.042	0.111	0.037	0.157	0.65	0.072	7.2
ST	0.128	0.107	0.057	0.111	0.131	0.140	0.111	0.123	0.052	0.96	0.134	13.4
TWI	0.128	0.107	0.173	0.111	0.131	0.140	0.111	0.123	0.157	1.181	0.131	13.1
Rf	0.128	0.107	0.173	0.111	0.131	0.140	0.111	0.246	0.157	1.304	0.144	14.4
DD	0.128	0.107	0.057	0.111	0.131	0.140	0.111	0.123	0.052	0.96	0.106	10.6
D-river	0.128	0.21	0.173	0.111	0.131	0.070	0.111	0.123	0.052	1.214	0.134	13.4
D-road	0.038	0.107	0.017	0.111	0.039	0.042	0.111	0.123	0.052	0.554	0.106	10.6

Table 4
Comparative matrices

Factors	El	Sl	LULC	ST	TWI	RF	DD	D-river	D-road	Sum_i	weight	Sum_i/ weight
El	0.124	0.112	0.144	0.106	0.131	0.144	0.106	0.134	0.183	1.184	0.124	9.54
Sl	0.124	0.112	0.216	0.106	0.131	0.144	0.106	0.067	0.061	1.067	0.112	9.52
LULC	0.062	0.033	0.072	0.106	0.039	0.043	0.106	0.040	0.183	0.684	0.072	9.51
ST	0.124	0.112	0.072	0.106	0.131	0.144	0.106	0.134	0.061	0.99	0.106	9.33
TWI	0.124	0.112	0.216	0.106	0.131	0.144	0.106	0.134	0.183	1.256	0.131	9.58
Rf	0.124	0.112	0.216	0.106	0.131	0.144	0.106	0.268	0.183	1.39	0.144	9.65
DD	0.124	0.112	0.072	0.106	0.131	0.144	0.106	0.134	0.061	0.99	0.106	9.33
D-river	0.124	0.224	0.216	0.106	0.131	0.072	0.106	0.134	0.183	1.296	0.134	9.67
D-road	0.037	0.112	0.021	0.106	0.039	0.043	0.106	0.040	0.061	0.565	0.061	9.27
Total												**85.4/9=0.48**

The El is elevation, Sl is slope, ST is Soil type, RF is Rainfall, DD is Drainage Density, Sumi is Sum index. The consistency index CI is equal to αmax -n/n-1 which is equal to 0.06 and the CR ratio 0.041 and it is less than 0.1 for large matrices, if it matches, then the pair-wise comparison matrix is said to be consistent.

Table 5
Flooding conditioning factors their classes, rating values, area coverage and percentage

Factor and weights	Class	Flood susceptibility (class)	Rating	Class pixels	Area Sq.km	%
Elevation (weight 12%)	28-86	Very high	5	1,347,533	1237	36
	87-130	High	4	1,414,329	1299	38
	140-210	Moderate	3	8,118,57	745	22
	220-360	Low	2	1,23,348	113	3
	370-790	Very low	1	5,350,0	49	1
Slope (weight 11%)	0-2.71	Very high	5	1,707,617	1565.48	44.41
	2.72-6.45	High	4	1,364,201	1250.65	35.48
	6.46-12.7	Moderate	3	5,626,26	515.79	14.63
	12.8-22.1	Low	2	1,367,91	125.4	3.56
	22.2-53.1	Very low	1	7,409,1	67.97	1.93
LULC (weight 10%)	Water	Very high	5	8,772,28	87.72	2.54
	Trees	Moderate	3	3,786,664	378.66	10.99
	Floods veg	High	4	4867	0.48	0.014
	Crops	Moderate	3	26070364	2607.03	75.78
	Built-up	High	5	1,659,462	165.94	4.81
	Bare ground	Moderate	3	7,736	0.77	0.022
	Range land	Moderate	3	2,028,710	202.87	5.89
Soil type (weight 10%)	Loam	Moderate	3	1,435,98	129.23	3.75
	Clay-Loam	Low	2	966,175	966.17	28.057
	Sandy-clay-Loam	Moderate	3	767,89	767.89	22
	Clay-Loam	High	2	1580.19	1580.19	45.89
TWI (weight 13%)	-8.4- -5	Very Low	1	1,461,921	1344.08	39.06
	-4.99- -2.99	Low	2	1,230,968	1131.74	32.89
	-2.98- -0.46	Moderate	3	5,554,709	509.99	14.82
	-.0459- 3.12	High	4	4,045,41	371.93	10.81
	3.13 - 13.8	Very High	5	8,995,5	82.704	2.4
Rainfall (weight 14%)	1012-1094	Very Low	1	6,564,99	590.84	17.15
	1095-1,131	Low	2	7,496,34	674.67	19.59
	1,132-1,116	Moderate	3	1,018,127	916.31	26.6
	1,167-1,200	High	4	7,68,300	691.47	20.08
	1,201-1,255	Very High	5	6,335,64	570.2	16.55
Drainage density km/Km^2 (weight 10%)	0-075	Very Low	1	1,347,533	1212.77	35.92
	0.76-1.2	Low	2	1,414,329	1272.89	37.7
	1.21-1.62	Moderate	3	8,118,57	730.67	21.64
	1.63-2.06	High	4	1,233,48	111.01	3.28
	2.07-4.21	Very High	5	5,350,0	48.15	1.426
Distance from River (m) (weight 13%)	0-1280	Very Low	5	1,134,887	1021.39	29.66
	1,290-2680	Low	4	1,037,238	933.51	27.109
	2690-4300	Moderate	3	8,356,61	752.09	21.84
	4310-6250	High	2	5,274,32	474.68	13.78
	6260-10,800	Very High	1	2,909,07	261.81	7.6
Distance from Roads (m) (weight 7%)	0-1,950	Very Low	5	1,276,312	1148.68	33.35
	1.960-4210	Low	4	1,142,383	1028.14	29.85
	4220-6710	Moderate	3	8,801,85	792.16	23
	6720-11,300	High	2	4,848,98	436.4	12.67
	11,400-19,900	Very High	1	4,234,7	38.11	1.1

The ascertained worth of the CR is 0.041, that is allowed to utilize the correlation for overlay with weights because it is not greater than 0.1.or 10%. The map of flood susceptibility of the Wyra catchment has been prepared with integrating nine theme maps for preventing flooding and shown in figure 8. The integrated overlay with weights system classifies the Wyra catchment into three classifications based on flood susceptibility such as high, moderate and low. Table 6 indicates the calculated areas of each susceptibility division of 11.60% (398.84 sq.km), 84.33% (2899.13 sq.km) and 4.06% (139.79 sq.km) categorized within the research field as high, moderate and low susceptibilities to flooding. Correspondingly, about 84% and 11.60% of the field of research are defined through moderate and very high susceptibilities to overflowing. Low susceptibility to flooding defines the remaining 4.06 % within the research region.

The regions with an extremely high risk of floods are principally controlled by low height, comparatively flat terrain, heavy rainfall, large TWI, more drainage density, crop lands and LULC. The regions with minimal flood susceptibility are principally controlled with highslopes and elevations, less drainage density, dense vegetation cover etc. and the outcomes are combined. To generate the map of flood susceptibility, the percentage of susceptibility to flooding is summarized in table 6.

Conclusion

Floods have caused extensive damage to social, environmental and human systems. Strategic planning tools such as flood risk assessment and simulation, are essential for mitigating flood risks and minimizing damages, even though they cannot be eliminated. This study aims to reduce the impact of flood damage by developing a flood susceptibility map for the Wyra catchment, utilizing GIS, RS and MCDA techniques, with the AHP ensuring model consistency.

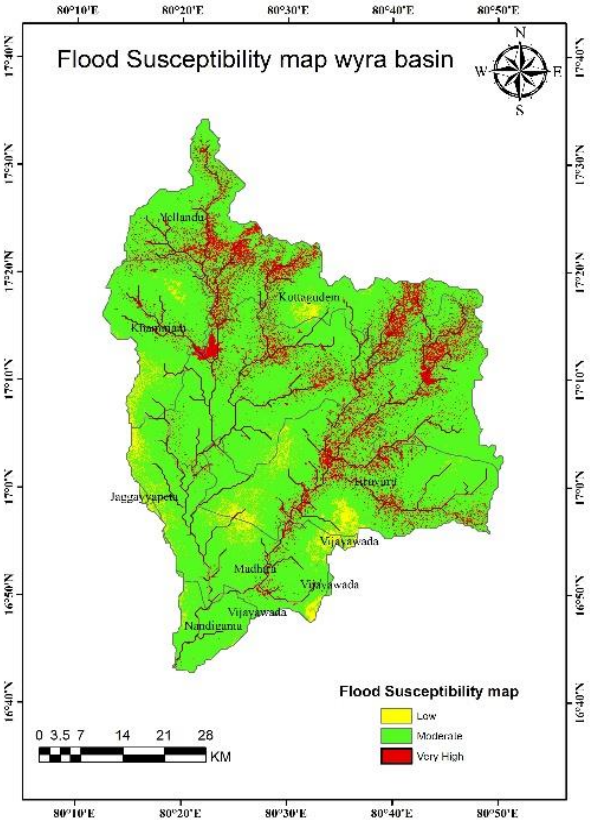


Fig. 8: Flood susceptibility map of the Wyra Catchment with three major classes: low, moderate and very high respectively

Table 6
Showing the regions and proportions of the Flood Susceptibility map

Flood susceptibility class	Class Pixels	Area (sq.km)	Percentage (%)
Low	152046	139.79	4.06
Moderate	3153308	2899.13	84.33
Very High	433816	398.84	11.60

Nine flood-controlling factors were identified including elevation, slope, LULC, soil type, TWI, rainfall, drainage density, distance from rivers and distance from roads. These factors were mapped, weighted and overlaid to determine areas vulnerable to flooding in the Wyra catchment.

The study revealed that elevation with a weight of 12%, significantly influences flood susceptibility. Areas between 28- and 86-meters elevation were particularly vulnerable, with 36% of the total area rated as having a very high susceptibility. The slope, weighted at 11%, with a range of 0 to 2.71 degrees, also played a critical role, covering 44.41% of the catchment with a very high flood susceptibility rating. LULC had a weight of 10%, with crops covering 75.78% of the catchment and receiving a moderate susceptibility rating. The TWI, weighted at 13%, indicated a very low flood susceptibility across 39.06% of the area, within a range of -8.4 to -5.

Rainfall, with a weight of 14%, indicated that 17.15% of the area, receiving between 1012 and 1094 mm of rainfall, was rated as having very low susceptibility. Drainage density, weighted at 10%, showed low susceptibility in 35.92% of the catchment, within a range of 0 to 0.75 km/km². The distance from the river, weighted at 13%, indicated that areas within 1290 to 2680 meters from the river, covering 27.10% of the area, had a low susceptibility rating.

The consistency of the pairwise comparison matrix was confirmed, with a consistency ratio of 0.041 and a consistency index of 0.06, both below the acceptable threshold of 0.1. The results showed that 11.60% of the study area had very high flood susceptibility, 84.33% had moderate susceptibility and 4.06% had low susceptibility. The regions with the highest flood potential were in the northeastern and northwestern parts of the Wyra catchment. This study demonstrates an effective and practical approach for identifying flood susceptibility zones. The findings can assist land use planners and decision-makers in implementing measures to reduce the risk of future flooding and associated damages.

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